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Characterization of Borrow Area Materials for the Bhaunrat Dam Project – A Case Study

Noor Shahid[1], Chitra R.[2], Gupta M.[3], Singh Amardeep[4]
[1]Corresponding Author and Scientist 'C', Central Soil and Materials Research Station, Ministry of Water Resources, RD & GR, Government of India, Olof Palme Marg, Hauz Khas, New Delhi-110016
[2, 3]Scientist 'E', Central Soil and Materials Research Station, Ministry of Water Resources, RD & GR, Government of India, Olof Palme Marg, Hauz Khas, New Delhi-110016
[4]Scientist 'D', Central Soil and Materials Research Station, Ministry of Water Resources, RD & GR, Government of India, Olof Palme Marg, Hauz Khas, New Delhi-110016

Abstract— *The geotechnical investigations play an important role in economic viability and structural stability of a dam project. The geotechnical investigation for dam project involves the borrow area investigations and foundation investigations. The borrow area locations and characteristics decide the economic viability of earthen dam project. Borrow area investigations characterizes the construction material in the vicinity of dam site, depth of construction material, extent of construction material. The foundation investigation is carried out to evaluate the compactness of foundation and abutments for the dam project, treatment to be given to foundation and depth of excavation of foundation. The extent of foundation investigation depends upon the site conditions but it provide the information regarding type of the soil or rock strata in the foundation or abutment at dam site, depth of rock, water table and locations of buried channels, seams, joints and fissures etc. The foundation investigations decide the structural safety of a dam project.*
The present paper presents the borrow area investigations carried out for construction of Bhaunrat Dam Project, Uttar Pradesh.

Keywords— *Earthen Dam, Borrow Area Investigations, Foundation Investigations, Trial Pits, Shear, Compaction, Consolidation, Dispersivity.*

Disclaimer: *The views expressed in this paper are strictly individual views of the author and do not, in any way, represent the views of the department/organization where they are presently working.*

I. INTRODUCTION

Bhaunrat Dam Project

The Proposed Bhaunrat Dam Project, Uttar Pradesh is planned across the river Jamuni (Batwa Basin) in Mahrauni Tehsil of Lalitpur District in Uttar Pradesh with 24 35'10'N latitude and 78 40'00'' E longitudes. The main purpose of dam is to provide the irrigation facilities of 16,000 hectare in the drought prone area of Bundelkhand region of Uttar Pradesh. The project envisages the construction of 22 m high earthen dam on the river Jamuni with a gross storage capacity of 45.08 MCM. The total length of dam is 4.2 km. The current geotechnical investigations were carried out for foundation investigations and construction materials of dam. Figure 1 presents the index plan of the Bhaunrat Dam Project, Uttar Pradesh

II. GEOLOGY OF THE RESERVOIR AREA

The dam site falls in Bundelkhand Province of Indian Peninsula. Bundelkhand Province is a triangular segment composed of rocks of Bundelkhand Granitoid Complex comprising granite-granodiorite, quartzo-feldspathic gneisses and enclaves of meta sedimentary and meta volcanic rocks, quartz reefs and dyke of dolerite. Beside the rock exposure of Bundelkhand Granitoid Complex (BGC), the dam area also comprises sediment of Banda Older Alluvium and Newer Alluvium. The Banda Older Alluvium lying over the BGC consists of red to deep brown sand with gravel lenses, silt and clay with kankar. The Newer Alluvium lies over the Banda Alluvium and further divided into Trace and Channel Alluvium.

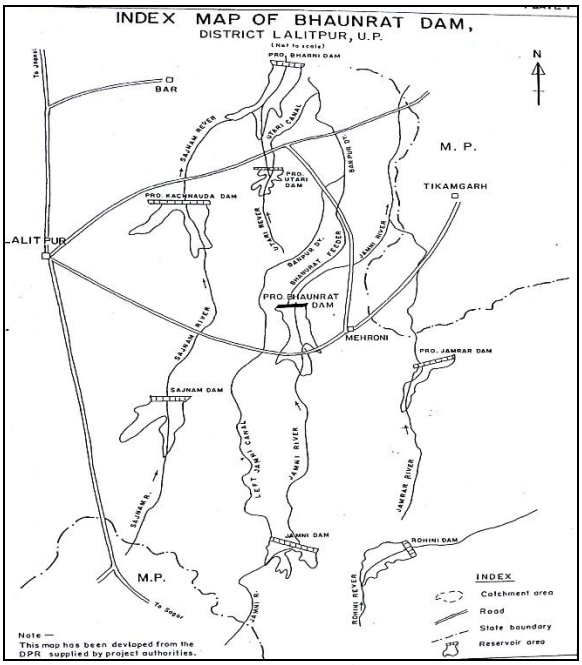

Fig. 1. Index plan of dam.

Geotechnical Investigations for the Borrow Area

The borrow area investigations for the dam project includes collection of representative soil samples from the trial pits of size 3m x 3m x 3m from the potential borrow areas. The collected soil samples are tested at CSMRS laboratory for ascertaining their suitability as construction materials for the earthen dam.

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Field Investigations

A total of eleven borrow area soil samples were collected from from the trial pits located on left and right side of the reservoir areas approximately 500 m in upstream of the dam axis for ascertaining their suitability as construction material. The soil samples were collected from a depth of 0.30 m to 3.00 m.

Laboratory Investigations

Mechanical Analysis and Atterberg Limits

All the 11 soil samples were subjected to Mechanical Analysis and Atterberg limits tests {as per SP-36 (Part-1)-1978}. The grain size analysis of the tested soil samples indicate that the tested soil samples in general possess predominantly silt sizes followed by the gravel sizes and clay sizes with few exceptions. The grain sizes of the tested soil samples indicate that the clay sizes vary from 9.1 % to 23.9 %, silt sizes vary from 32.7 % to 57.0 %, fine sand sizes vary from 1.7 % to 16.8 %, medium sand sizes vary from 1.5 % to 13.3 %, coarse sand sizes vary from 0.2 % to 7.7 % and the gravel sizes vary from 10.3 % to 37.7 %. The plasticity index values of the tested soil samples indicate that all the tested soil samples in general possess medium plasticity characteristics. Based on the results of grain size distribution and Atterberg limits tests, out of the 11 tested soil samples, 9 soil samples fall under CI (Clay with Medium Compressibility), one soil sample each falls under CL (Clay with Low Compressibility) and GC (Clayey Gravel) group of Bureau of Indian Standard soil classification system (IS:1498-1970). The graphical representations of grain size distribution of the tested soil samples are presented in Figure 2.

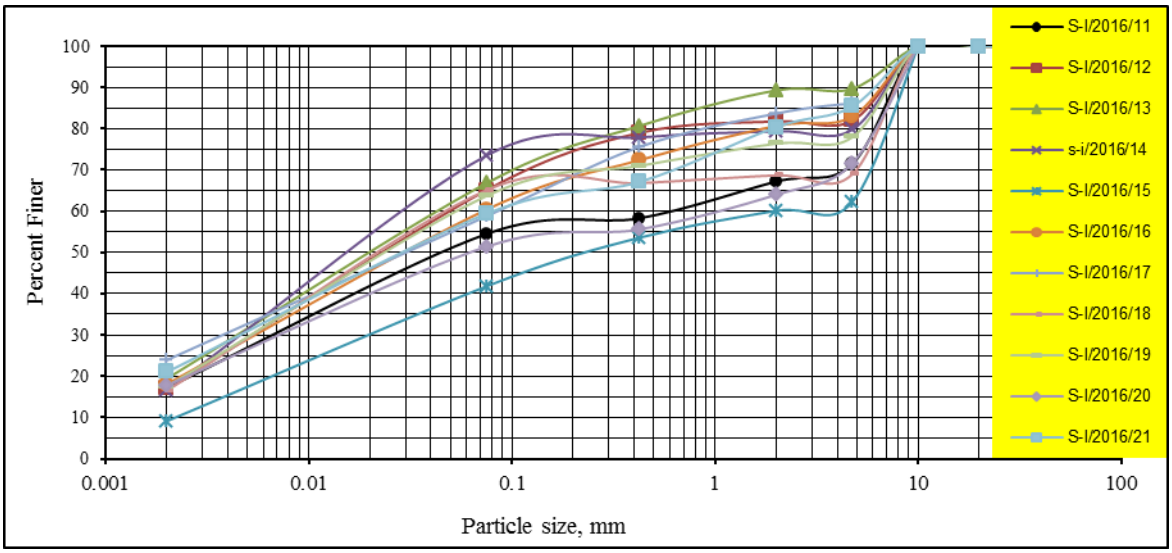

Fig. 2. Grain size distribution curve.

Shrinkage Limit

Four selected soil samples were subjected to Shrinkage Limit test. The values of shrinkage limit of the tested soil samples vary from 14.7 % to 19.3 % and are presented in Table 1.

TABLE 1. Shrinkage limit and specific gravity test results.

Sample No.	Shrinkage limit, %	Shrinkage ratio	Volumetric Shrinkage,%	Specific Gravity
S-III/2016/11	16.9	1.93	40.2	2.66
S-III/2016/12	19.3	1.89	26.9	2.64
S-III/2016/19	14.7	2.01	56.7	2.66
S-III/2016/20	15.2	2.02	50.9	2.65

Standard Proctor Compaction

Six selected soil samples were subjected to Standard Proctor Compaction test. The test was carried out on the material passing 4.75 mm IS Sieve. The values of Maximum Dry Density and Optimum Moisture Content of the tested soil samples vary from 1.740 g/cc to 1.775 g/cc and 14.8 % to 18.4 % respectively. The graphical representations of the Standard Proctor Compaction test results of the tested materials are presented in Figure 3.

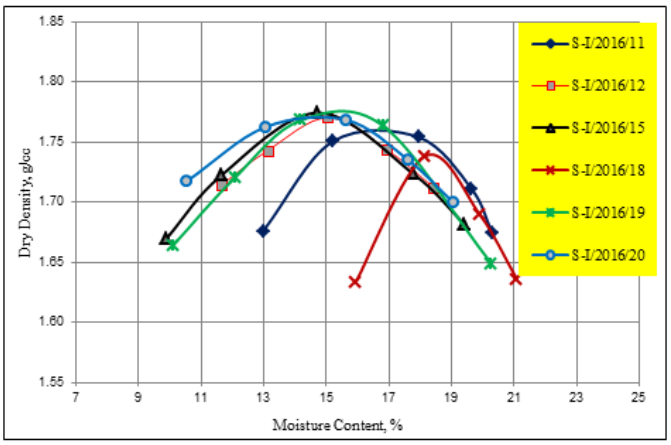

Fig. 3. Standard proctor compaction curve.

Specific Gravity

Six soil samples were subjected to Specific Gravity test. The Specific Gravity values of the tested soil samples vary from 2.64 to 2.66 and are presented in Table 4.

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Triaxial Shear

Four selected soil samples were subjected to Consolidated Undrained Triaxial Shear tests with pore water pressure measurement. The test was carried out on the material passing 4.75 mm IS Sieve. The soil samples were compacted at 98% of the maximum dry density, consolidated and sheared under four different constant effective confining pressures of 1, 2, 3 and 4 kg/cm^2 respectively after achieving full saturation by back pressure. The total shear strength parameters total cohesion (c) and total angle of shearing resistance (ϕ) of the tested soil samples vary from 0.20 kg/cm^2 to 0.44 kg/cm^2 and 13.3° to 27.4° respectively. The effective shear strength parameters effective cohesion (c′) and effective angle of shearing resistance (ϕ') of the tested soil samples vary from 0.10 kg/cm^2 to 0.22 kg/cm^2 and 20.5° to 37.5° respectively. The results of Triaxial Shear tests - Consolidated Undrained with pore water pressure measurement of the tested soil samples are presented in Table 2.

One Dimensional Consolidation

Three selected soil samples were subjected to One Dimensional Consolidation test for ascertaining its consolidation and compressibility characteristics. The test was carried out on the materials passing 2.0 mm IS sieve size. The soil samples were compacted at 98% of the maximum dry density and tested at different stress levels viz. 0.25, 0.5, 1.0, 2.0, 4.0 and 8.0 kg/cm^2 respectively. The test results indicate that the tested soil samples exhibit medium compressibility characteristics. The consolidation test results are presented in Tables 3 to 5.

TABLE 2. Triaxial shear test results.

Sample No.	Triaxial Shear Test			
	Total shear parameter		Effective shear parameter	
	c kg/cm^2	ϕ Degrees	c′ kg/cm^2	ϕ' Degrees
S-III/2016/11	0.44	27.4º	0.17	31.6º
S-III/2016/12	0.21	17.9º	0.12	37.5º
S-III/2016/19	0.35	13.3º	0.22	27.ºº8
S-III/2016/20	0.20	13.8º	0.10	20.5º

TABLE 3. Consolidation test results, C_v.

Sample No.	Coefficient of Consolidation, $C_v \times 10^{-4}$ cm^2/kg				
	Stress level, kg/cm^2				
	0.25-0.50	0.5-1.0	1.0-2.0	2.0-4.0	4.0-8.0
S-III/2016/11	10.80	7.06	5.11	3.65	2.27
S-III/2016/12	13.02	9.18	5.71	4.34	3.20
S-III/2016/20	6.46	3.51	2.02	1.36	0.91

TABLE 4. Consolidation test results, m_v.

Sample No.	Coefficient of Volume Compressibility, $m_v \times 10^2$ cm^2/kg				
	Stress level, kg/cm^2				
	0.25-0.50	0.50-1.0	1.0-2.0	2.0-4.0	4.0-8.0
S-III/2016/11	2.75	2.69	2.07	1.43	1.00
S-III/2016/12	1.88	1.62	1.36	1.03	0.83
S-III/2016/20	3.19	2.99	2.37	1.73	1.25

TABLE 5. Consolidation results, C_c & C_s.

Sample No.	Compression Index, C_c	Swelling Index, C_s
S-III/2016/11	0.1696	0.0168
S-III/2016/12	0.1323	0.0150
S-III/2016/20	0.2011	0.0216

Laboratory Permeability Test

Four selected soil samples were subjected to the laboratory permeability test using falling head method. The test was conducted on the material passing 4.75 mm IS Sieve. The soil samples were compacted at 98% of the maximum dry density. The results of laboratory permeability test indicate that all the four tested soil samples possess impervious drainage characteristics. The laboratory permeability test results are presented in Table 6.

Soil Dispersivity Identifications Test

Two selected soil samples were subjected to the soil dispersivity identification tests viz. Sherard's Pinhole, SCS Double Hydrometer, Crumb test and Chemical Analysis of pore water extract for arriving at their dispersivity characteristics. The consensus arrived at based on the above mentioned four special soil dispersivity identification tests indicate that both the tested soil samples fall under non dispersive zone. The consensus arrived at based on the soil dispersivity identifications test is presented in Table 7.

Chemical Analysis

Four selected soil samples were subjected to chemical analysis with particular reference to PH, CaCO3, Total Soluble Solids, Water Soluble Sulphates, Water Soluble Chloride and Organic Matter. The test results of chemical analysis indicate the normal behavior of soil.

TABLE 6. Laboratory permeability test results.

Sample No.	Coefficients of Permeability	Drainage Characteristics
S-III/2016/11	4.72 × 10-7	Impervious
S-III/2016/12	1.83 × 10-7	Impervious
S-III/2016/19	3.42 × 10-7	Impervious
S-III/2016/20	1.21 × 10-7	Impervious

TABLE 7. Soil dispersivity identifications test results.

Sample No.	Pinhole Test	SCS Dispers-ion Test	Crumb Test	Chemical Analysis of Pore Water Extract	Consensus
S-III/2016/11	◯	◯	◯	◯	◯
S-III/2016/20	◯	◯	◯	◯	◯

◯ Non Dispersive ⦶ Intermediate ● Dispersive

III. CONCLUSION

Based on the findings of the laboratory investigations carried out on the soil samples collected from the borrow areas for the Proposed Bhaunrat Dam Project, Uttar Pradesh, the following conclusions have been arrived at.

- The grain size analysis of the tested soil samples indicate that the tested soil samples possess predominantly silt sizes followed by the gravel sizes and clay sizes.
- The plasticity index values of the tested soil samples indicate that all the soil samples in general possess medium plasticity characteristics.
- Based on the results of grain size distribution and Atterberg limits tests, out of the 11 tested soil samples, 9 soil samples fall under CI (Clay with Medium

Compressibility), one soil sample each falls under CL (Clay with Low Compressibility) and GC (Clayey Gravel) group of Bureau of Indian Standard soil classification system.

- The values of Maximum Dry Density and Optimum Moisture Content of the tested soil samples vary from 1.740 g/cc to 1.775 g/cc.
- Based on the Standard Proctor Compaction tests, it is inferred that the tested soil samples are capable of achieving good/very good compaction densities.
- The total shear strength parameters total cohesion (c) and total angle of shearing resistance (ϕ) of the tested soil samples vary from 0.20 kg/cm^2 to 0.44 kg/cm^2 and 13.3° to 27.4° respectively. The effective shear strength parameters effective cohesion (c') and effective angle of shearing resistance (ϕ') of the tested soil samples vary from 0.10 kg/cm^2 to 0.22 kg/cm^2 and 20.5° to 37.5° respectively.
- Based on the results of triaxial Shear tests conducted on the soil samples, it is inferred that the tested soil samples are likely to exhibit good/very good shear strength characteristics.
- Based on the one dimensional consolidation test conducted on the soil samples, it is inferred that borrow area materials are likely to undergo medium compressibility depending upon the imposed loads.
- The results of laboratory permeability test indicate that the tested soil samples possess impervious drainage characteristics.
- The consensus arrived at based on the above mentioned four special soil dispersivity identification tests indicate that all the tested soil samples fall under Non Dispersive zone.

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